First Workshop on Wireless Sensing: Proceedings

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U.S. DEPARTMENT OF COMMERCE Technology Administration National Institute of Standards and Technology 100 Bureau Drive Gaithersburg, MD 20899



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First Workshop on Wireless Sensing

Proceedings

Sensors Expo & Conference

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1 Overview of the Wireless Sensing Workshop

The first Wireless Sensing Workshop was held on June 4, 2001, at the Sensors Expo/Conference at the Rosemont Convention Center in Chicago, IL. The National Institute of Standards and Technology (NIST), SENSORS magazine, Sensors Conference, and Institute of Electrical and Electronics Engineer (IEEE) Instrumentation and Measurement Society's Technical Committee on Sensor Technology (TC-9) cosponsored the workshop. NIST is an agency of the U.S. Department of Commerce's Technology Administration. Its mission is to help increase U.S. industry competitiveness through advanced research, standards, and technology collaboration.

Recently, there has been considerable interest from industry and government in applying wireless technology to sensor-based applications. This is due primarily to the prolific phenomenon of Bluetooth, a wireless technology being developed by a 1200-member industrial consortium. According to earlier Bluetooth industry predictions, a billion Bluetooth wireless devices may be in use all over the world within five years. Bluetooth technology providers indicated that they could provide low cost, seamless integration of wireless devices from home automation to mobile systems, office automation, manufacturing facilities, and field operations. Other technology, such as Ethernet, has become dominant in network communication, and its usage is becoming increasingly popular in manufacturing. Wireless Ethernet has been moving from office automation into other application areas, including home and factory automation. Sensor companies have begun developing and applying these standard interfaces to sensor applications. The US Navy has also expressed interest in wireless sensor connectivity aboard naval vessels to enhance overall system performance, reduce manpower, and increase efficiency.

The Sensor Development and Application Group at NIST has been working with industry and IEEE to establish IEEE 1451, titled A Standard for a Smart Transducer Interface for Sensors and Actuators. In response to the industry's interest in wireless sensing, NIST initiated, cosponsored, and conducted this workshop to explore this level of interest. In addition, state-of-the-art, wireless communication technologies were examined. This workshop provided a good opportunity for representatives from industry, academia, and government to discuss the possibility of a standard for wireless sensing in an open forum. Ninety people attended the workshop to represent the manufacturing, process control, aerospace, home automation, automotive, and government sectors. The ratio of attendees was approximately 4/2/1 for users/sensor vendors/network vendors, respectively.

The workshop opened with an overview of the IEEE 1451 standard. NIST's reference implementation of the IEEE 1451.1 smart transducer information model and the investigation of interfacing the 1451.1 model to the wireless world were discussed. Then various wireless technologies such as the wireless Ethernet standard (IEEE 802.11x) and Bluetooth were presented in detail. Following that, hardware and software tools that could help speed up wireless application development, as well as the application of wireless Bluetooth technology for sensors, were presented. One presentation proposed a wireless sensor interface standard, a potential IEEE P1451.5, using the IEEE 802 as a guideline for managing the IEEE 1451 framework.

After briefing the attendees on various communication interface standards, an open forum discussion began. Attendees were encouraged to provide input regarding their needs and general

requirements for a wireless sensor communication interface. The results of the discussions are presented in Section 2: Issues & Discussions.

The open forum appeared to be successful in determining the appropriateness of various wireless communication technologies for sensor interfacing. It has also begun the dialogue in assessing the general wireless requirements of sensor manufacturers and users. By the request of the attendees, a follow-up wireless sensor workshop has been scheduled for October 4, 2001, at the next Sensors Expo/Conference in Philadelphia, PA. Together we will further examine other technologies and begin pursuing the IEEE procedure for organizing a working group for developing a wireless communication interface standard for sensors.

2 Issues & Discussions

Why use wireless at all?

Some attendees at the conference questioned whether wireless communications for sensors should even be considered at all. For applications such as high-speed process control, wireless might not be the best solution. In those cases, wired, dedicated sensors may be the best solution. However, in many cases where processes exist over a large facility or are low enough speed, wireless may be a best-fit solution since the cost of cabling can be exorbitant when compared to the cost of the sensor itself.

What is data reliability and how does it affect wireless sensors?

Data reliability was the largest issue raised during the workshop. Data reliability depends on three factors: availability of the wireless signal, integrity of the data message, and confidentiality of the data message. These three factors were brought up in many different forms all throughout the presentations and discussions at the workshop.



Availability of the wireless signal is the physical side of the reliability triangle. Some issues related to the availability are range, interference, and data throughput. "Range is everything!" By increasing the range of a signal, the signal is less prone to multi-path effects and small signal interference. "The good news about the ISM band is you don't need a license. The bad news is nobody else does either." Many of the wireless sensors available or being developed use the Industrial, Scientific and Medical (ISM) bands for their transmission. This allows them the freedom of not relying on the Federal Communications Commission (FCC) for regulation of signal. However, it also limits power and sole proprietorship for a particular bandwidth. Many of the data transmission algorithms used today have compensation built-in to overcome interference in some way. Some of the standards developed for wireless communications allow multiple data throughput speeds to be used depending on the distance between the transmitter and receiver. IEEE 802.11b allows the throughput to step down from 11 Mega bits per second (Mbps) to 5.5 Mbps to 1 Mbps if the two systems begin to move outside the recommended operating range.

Data integrity and confidentiality are the software components of the reliability triangle. In order for modern wireless communications to send reliable data from one place to another, the integrity of that data needs to be checked. Data integrity basically establishes that the bits you send get to the receiver and that they receive the correct bits of data. Many of the wireless communication algorithms developed today have some sort of data integrity or error correction

checks built-in, such as cyclical redundancy checks (CRC). More complicated algorithms use some sort of forward error correction that allows for correcting errors without requesting the signal be sent again. These algorithms can increase the effective bandwidth of a communication link, since there are fewer requests for re-transmission made by the devices on the network. The IEEE 1451.2 specification for a Transducer Electronic Data Sheet (TEDS) has error correction built-in using a checksum, but requires the user to include their own error detection code if they want a more complicated algorithm.

Data confidentiality relates to the security of the signal being sent from one system to another. This can be an important feature of some wireless communication systems, since companies worry about having their data co-opted by a competitor. As more and more data is stored and moved digitally, industrial espionage has become an ever more present threat to companies.

What are user's particular bandwidth requirements?

An informal survey of the bandwidth requirements for workshop attendees was conducted. The results are as follows.

| Bandwidth | Interested Parties |
|---------------------|--------------------|
| <= 300 bps | 63% |
| 300 bps – 50 kbps | 25% |
| 50 kbps – 250 kbps | 3% |
| 250 kbps – 1.5 Mbps | 6% |
| > 1.5 Mbps | 3% |

Where should the wireless communications be located?

Many of the attendees at the workshop were of the opinion that the wireless communications should not be included directly on the sensors for cost reasons as seen in Figure 1. Smart Transducer Interface Modules (STIMs) as defined in IEEE 1451.2 consist of sensors and/or actuators, signal conditioning circuit and digital data output. The attendees decided that it would be better to have sensors attached to some sort of wireless NCAP node as shown in Figure 2, which then communicate to a wired network via a gateway. Network Capable Application Processor (NCAP) is defined in the IEEE 1451.1 as a sensor network node.

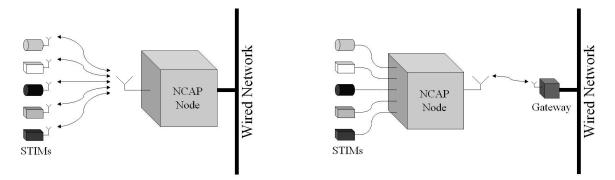


Figure 1 - Wireless STIMs

Figure 2 - Wireless NCAP Node

How many devices per node do users require?

NCAP nodes allow multiple sensors to be attached to the network using one common point of access. These allow for the communication portion of the sensor network to be taken out of the sensors themselves and distributed between multiple sensors via a separate piece of hardware. An informal survey was taken of the numbers of sensors for each node. The results are as follows.

| Sensors/Node | Interested Parties |
|--------------|--------------------|
| 8 | 26% |
| 32 | 53% |
| 256 | 21% |

How does wireless transmission power affect battery lifetime and safety?

Another issue raised at the workshop had to do with the power requirements of some of the wireless communication standards. Some of them require "high" power (100 mW), which may not be available in small battery operated sensors. The expected battery life of some of the planned sensor needs to be on the order of years, which limits the power consumption allowed for the communication system. Replacing batteries in some machines may not be as easy as it would be for a typical cell phone.

There are also issues of the intrinsic safety of such "high" power communications when used in hazardous environments. The Occupational Safety and Health Administration (OSHA) has restricted the use of wireless Ethernet in chemical plants and refineries for the lack of safety certifications. Wireless communication is also not allowed for fail-safe systems such as emergency stop systems where lives are at stake.

How can wireless sensors benefit from the "hot" wireless technology?

During the workshop presentations, the topic of cost was brought up related to both the basic chip sets for and devices using different wireless communication standards. Although the Bluetooth and 802.11b standards may not be the best fit for all applications in the sensor community, the fact that devices using the chip sets based on these standards are developed in mass quantities for the mobile computing community means that the chip sets will come down in price due to economy of scale. With custom application specific integrated circuit (ASIC) chips for wireless communications, the best algorithms for a particular application could be implemented, however, the device would cost considerably more due to the development cost of the chip set itself. Although the IEEE 1451 standard is being developed for most applications, it should not eliminate such standards as Bluetooth and 802.11b due to their enormous backing and potential in wireless communications.

Even though the production chip sets for a particular wireless communication standard may be inexpensive, the cost for the development system may be thousands of dollars. This cost could easily be amortized if a company plans to sell thousands of units, but if it plans to be a custom design house, it may be prohibitively expensive to make up for the startup costs for these standards.

How can sensors be reconfigured in place?

Some devices may require different communication speeds for different tasks. Configuring the device initially or upgrading the device's software may require a high-speed 2-way link that allows for a large amount of data to be transmitted all at once. Once the device starts operating normally, it may only require a small amount of bandwidth, especially if the sensor has some intelligence built-in.

What if more than one system needs the sensor data simultaneously?

The question about whether the communication should be broadcasted or targeted came up. Broadcast communications allow one producer to broadcast its information to multiple receivers without knowing who they are or how many receivers are listening. Although this may be good in some cases, it is not appropriate in all cases. Many networks do not allow this type of communication, so the issue will need to be addressed. As of yet, it has not been brought up in the IEEE 1451 standard.

Can multiple wireless sensors synchronize their data at high speed?

Event synchronization may be difficult at less than 1 ms using standard wireless communications. Some standards have built-in time synchronizing capabilities due to the fact that they must do something every so often in order to stay as part of the network. Bluetooth devices, for example, must hop frequencies every 625 μs, making synchronizing at 1 ms very easy. To go much farther down would take a special timing chip set on the device that is capable of special synchronization in order to coordinate multiple devices. A proposed IEEE P1588, titled A Standard for Precise Clock Synchronization in Networked Measurement and Control Systems, is being developed in the IEEE Instrumentation and Measurement Society's Technical Committee on Sensor Technology to address this kind of issue.

Can the NCAP and STIM Be Combined?

As specified in the standard, IEEE 1451.2 defined a physical 10-wire connection between the NCAP and STIM. This was done to allow the plug and play of sensors and networks from different manufacturers. However, the standard does not preclude the NCAP and STIM to be colocated inside the same chip. In such configuration, the interface between the NCAP and STIM is not exposed for consideration of plug and play, therefore the 10-wire interface is not important or necessary.

Can the ISM bands support the extra users?

The FCC has certain bandwidths that it has declared open to unlicensed equipment as long as that equipment stays within certain power requirements. These bandwidths are called the ISM bands, and many wireless communication devices use these bands. Here is a listing of some of the ISM bands and devices that use those bands:

- 900 MHz Cell phones, portable phones, home electronics, spread spectrum communications
- 2.4 GHz Portable phones, spread spectrum communications
- 5 GHz Satellite communications

Topics for Further Discussion:

Are multiple versions of the IEEE 1451 wireless standard needed?

It may be necessary to look into multiple flavors of a wireless IEEE 1451. There seems to be enough differences between the low and high-speed sensor communities that multiple standards within the IEEE 1451 framework may be necessary to meet the needs of the two worlds, unless there is a way to define the specification to accommodate the requirements of both groups. This can be a way to break out discussions of power consumption as well, since the high-speed community may not have the same requirements for power consumption as the low-speed community.

Although there were some negative comments, many workshop attendees seemed open to the idea of creating a wireless version of IEEE 1451. A general comment was that the IEEE 1451 committee had done a very good job developing a standard for smart sensors. Enough interest had been developed in the industry that more manufacturers and users were looking into the standard for their particular applications.

Should there be another workshop organized?

There are multiple upcoming conferences, and it would be good to organize a follow-up workshop at one of these. The possible candidates include:

September 10-13, 2001 ISA 2001, Houston, TX

• October 2-4, 2001 Sensors Expo, Philadelphia, PA

• November 5-7, 2001 SIcon 2001, Chicago, IL

The next workshop is scheduled to be held on October 4, 2001 at the Sensors Expo/Conference in Philadelphia, PA. At the follow-up workshop, a strawman should be developed for applying the IEEE 1451 to a particular wireless sensor application in order to help develop the standard further. Also, some tools for developing the standard should be discussed. These tools can be either hardware tools such as very high density layout (VHDL) development packages or software tools such as unified modeling language (UML) and object-oriented design tools.

How will the proceedings for this workshop be distributed?

Information about this workshop and its proceedings will be made available in both electronic and paper form. Electronic forms can be obtained on compact disk (CD) and from the web. The web address for information is http://ieee1451.nist.gov.

3 Presentations

3.1 Wireless Sensing and IEEE 1451

Wireless Sensing Workshop



Wireless Sensing and IEEE 1451

Sensors Conference / Expo 2001 June 4, 2001

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National Institute of Standards and Technology United States Department of Commerce

K. Lee, NIST, 6/4/01

Wireless Sensing Workshop



Outline

- Objectives of the Wireless Sensing Workshop
- Introduction / Background
- State of Industry on Sensor Interfaces
- Sensor Interface Standardization-IEEE P1451
- Summary of IEEE P1451
- Interest in Wireless Sensors
- Acknowledgment



Objectives of the Wireless Sensing Workshop

- Review the latest wireless technologies and their applications.
- Provide an open forum for examining and discussing the appropriateness of these and other technologies for use as wireless sensor interfaces.
- Discuss the requirements of wireless sensor communication interfaces.
- Use previous IEEE P1451 model and experience to explore wireless interface standardization.
- Charter a future action plan

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Wireless Sensing Workshop



Introduction / Background

- The National Institute of Standards and Technology (NIST) is part of the Department of Commerce's Technology Administration.
- NIST's Mission: To help increase U.S. industry competitiveness through advanced research, standards, and technology collaboration.
- The Sensor Development and Application Group at NIST has been working with industry and IEEE - establishing the Smart Transducer Interface Standard, IEEE 1451.



State of Industry on Sensor Interfaces

- Smart features integrated into sensors and actuators.
- Increasing uses of digital communication and networked configurations for connecting sensors and actuators.
- The trend is moving toward distributed measurement and control, and distributed intelligent sensing architecture.
- Networked sensor technology applied to commercial and consumer applications in
 - process control,
 - industrial automation,
 - automotive,
 - aerospace,
 - to smart buildings and homes
 - etc...

K. Lee, NIST, 6/4/01

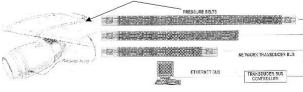
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State of Industry - cont'd

- · Networked sensors are needed
 - Example: US Navy needs tens of thousands of networked sensors per vessel to enhance automation because of the reduced-manning program.
 - Example: Boeing needs to network hundreds of sensors to monitor and characterize airplane wing performance.
 Boeing would benefit by using networked sensors and actuators to reduce the amount of wiring.





Picture courtesy IEEE

Pictures courtesy Endevco



State of Industry - cont'd

Barriers:

- Large number of different networks to support.
- Significant sensor interface software development for each network.
- Lack of network software know-how and support by sensor manufacturers.
- Lack of a standardized sensor interface.
- These hold back the speedy development and adoption of smart sensors.

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Why Networking Sensors?

Networking sensors provides advantages not readily available with traditional sensors, they:

- significantly lower the total system cost by simplified wiring
- enable self-describing of sensors
- allow multi-variable sensor configuration
- enable time stamp of the measurements
- enable embedded processor or ASIC implementation
- ease software configurability
- enable bi-directional digital communication
- communicate messages in standardized digital format
- provide Internet connectivity, thus global, or anywhere, access of "sensor information"



Sensor Interface Standardization - IEEE P1451

- A set of standards aimed to simplify transducer (sensor or actuator) connectivity.
- It is developed as:
 - an <u>open</u>, industry consensus standard with participation from sensor, measurement, and control network industries, and users.
- It's purposes are to:
 - provide a set of common interfaces for connecting sensors and actuators to <u>existing</u> instruments, and control and field networks.
 - provide an easy upgrade path for connecting transducers, instruments, or networks from <u>any</u> manufacturer.

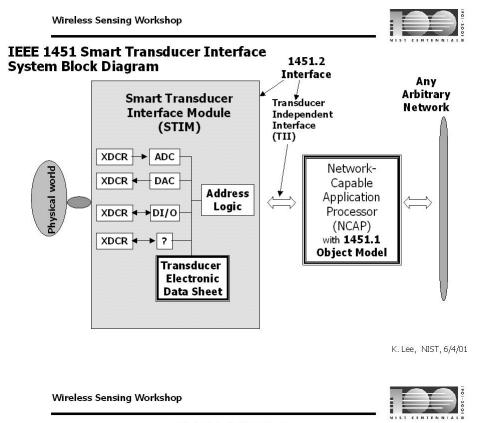
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What Standards are being developed?

- IEEE Std 1451.1-1999, Network Capable Application Processor (NCAP) Information Model for smart transducers
 -- Published standard.
- IEEE Std 1451.2-1997, Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats -- Published standard.
- IEEE P1451.3, Digital Communication and Transducer Electronic Data Sheet (TEDS) Formats for Distributed Multidrop Systems -- Being developed.
- **IEEE P1451.4**, Mixed-mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats -- Being developed.



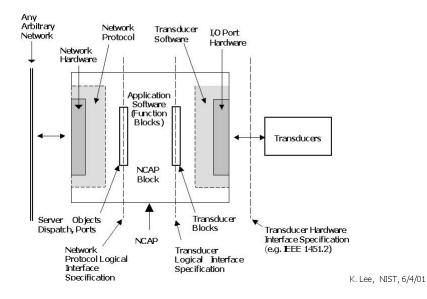
IEEE 1451.1 NCAP Information Model for Smart Transducers

By defining a common object model for the components of a networked smart transducer, together with interface specifications to these components, the Standard provides:

- Network protocol logical interface specification (via Server Object Dispatch and Ports)
 - Software interfaces between application functions in the NCAP and the network in a manner independent of any specific network
- Transducer logical interface specification (via Transducer Block)
 - Software interfaces between application functions in the NCAP and the transducers in a manner independent of any specific transducer driver interface



IEEE 1451.1 Networked Smart Transducer Model



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IEEE 1451.2 Transducer Electronic Data Sheet (TEDS)

Meta-TEDS

- Data structure related information
 - · version number
 - · number of implemented channels
 - · future extension key
 - ...

- Identification related information

- manufacturer's identification
- · model number
- · serial number
- revision number
- date code
- · product description
- ...



IEEE 1451.2 Transducer Electronic Data Sheet (TEDS)

Channel TEDS

- Transducer related information
 - lower range limit
 - upper range limit
 - · physical unit
 - unit warm-up time
 - uncertainty
 - · self test key
 - ...

- Data Converter related information

- · channel data model
- · channel data repetitions
- · channel update time
- · channel read setup time
- · channel write setup time
- data clock frequency
- · channel sampling period
- trigger accuracy
- •

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IEEE 1451.2 Transducer Electronic Data Sheet (TEDS) -

Calibration TEDS

- Data structure related information
 - · Calibration TEDS length
- Calibration related information
 - · last calibration date-time
 - · calibration interval
 - number of correction input channels
 - · multinomial coefficient
 -

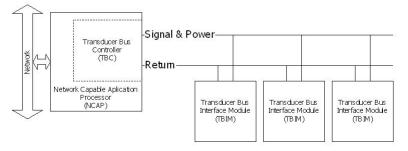
- Data integrity information

• checksum for calibration TEDS



IEEE P1451.3 Distributed Multidrop System

- Synchronously reads large arrays of sensors at high speed in a parallel transducer bus setting.
- Supports sensors with bandwidth requirements to several hundred kilohertz and time correlation requirements in the range of nanoseconds.



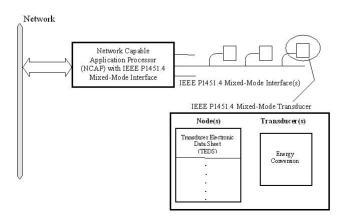
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IEEE P1451.4 Mixed-mode Transducer and Interface

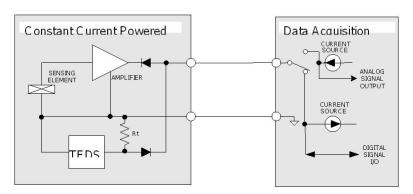
- simple, low-cost connectivity (2-4 wires) of analog sensors with TEDS.
- Support existing or legacy data acquisition systems with TEDS.





IEEE P1451.4 Mixed-mode Interface

Using Two- Wire Scheme for sending Digital TEDS and Analog Data



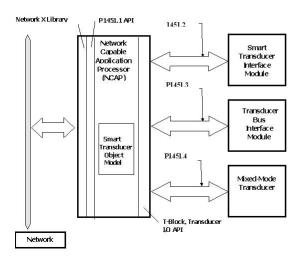
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Summary

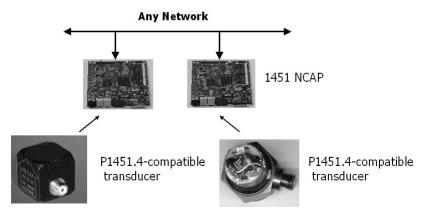
IEEE P1451 Family Member Independence

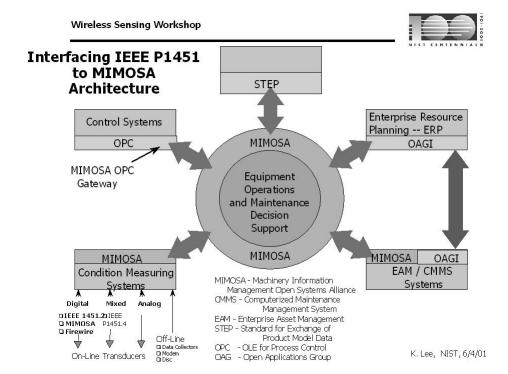


- The proposed standards are being designed to work with each other.
- However, each proposed standard can also be used by itself, independent of the others.

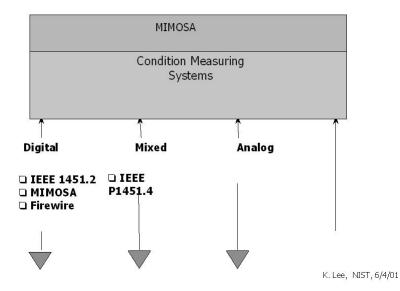


IEEE P1451 Enables "Plug and Play" of Transducers to networks







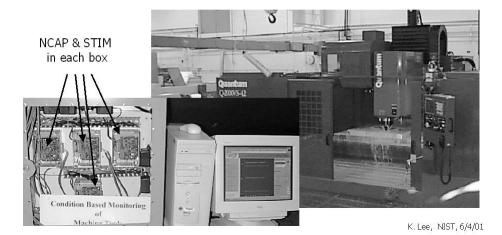


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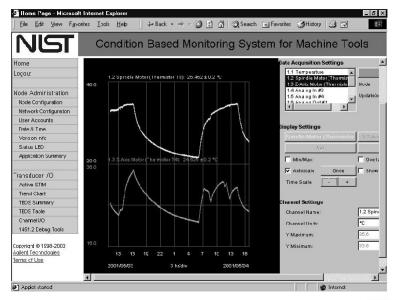


Machine Condition Monitoring in the Shop

- Temperature sensors monitor spindle motors, bearings, axis drive motors.
- Allow monitoring of sensors over the Internet via any common web browser.







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Wireless Technology is Here

- Traditional proprietary wireless communication protocols could be expensive to implement.
- Wireless capability is being designed into laptop computers, desktop computers, personal data adapters (PDA), and hand-held computers and devices.
- The popular wireless standards are Bluetooth (or IEEE P802.15) and Wireless Ethernet (IEEE 802.11b).
- Wireless communications have revolutionized the cellular phone industry and provide low-cost electronics for a mass market. This could provide a low-cost base for possible wireless sensor applications.



Interest on Wireless Sensors in Industry

- Machinery condition-based monitoring is one of many examples that can use wireless sensor technology,
 - quick installation and thus reduced installation cost.
 - improve ability to easily and quickly re-configurate the data acquisition and control system.
 - ability to connect measurement data to the Internet.
- Industrial Automation Study Group of the Bluetooth Special Interest Group (SIG) is in full action pursuing the establishment of a working group.
- Question: Can we use existing wireless technologies for sensor connectivity in a networked environment?

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Acknowledgment

 Thanks to Sensors Magazine, IEEE I&M Society and NIST for their support and co-sponsorship of the workshop.

3.2 Implementing IEEE 1451.1 at NIST in a Wireless Environment



Implementing IEEE 1451.1 in a Wireless Environment

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Introduction



- Who we are: NIST mission is to help increase US industry competitiveness through advanced research, standards, and technology collaboration
- Member of the Sensor Development and Application Group (SDAG) within the Manufacturing Engineering Laboratory (MEL) at NIST
- Member of the Working Group on the IEEE Standard for a Smart Transducer Interface for Sensors and Actuators — Network Capable Application Processor (NCAP) Information Model, or IEEE 1451.1 ("dot1")

Topics of Discussion



- Part 1: Provide a brief object-based overview of the IEEE 1451.1 components, services, and block classes
- Part 2: Discuss the technical and architectural solutions for the development and deployment of the NIST IEEE 1451.1 reference implementation
- Part 3: Illustrate the use of IEEE 1451.1 in an example application using both the NIST C++ and Java reference implementations
- Part 4: Describe an IEEE 802.11b (11Mbps) wireless environment used for application testing and demonstration

Implementing IEEE 1451.1 in a Wireless Environment

IEEE 1451 Overview/Goals



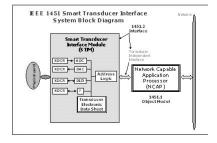
- Provide standardized communication interfaces for smart transducers, both sensors and actuators. In the form of a standard hardware and software definition/specification.
- Simplify the connectivity and maintenance of transducers to device networks through such mechanisms as common Transducer Electronic Data Sheet (TEDS) and standardized Application Programming Interfaces (API)
- Allow plug-and-play with 1451 compatible transducers among different devices using multiple control networks
- Give sensor manufacturers, system integrators, and endusers the ability to support multiple networks and transducer families in a cost effective way

Part 1: IEEE 1451.1 Overview/Goals



IEEE Standard for a Smart Transc Interface for Sensors and Actualy

- "The specifications provide a comprehensive data model for the factory floor, and a simple application framework to build interoperable distributed applications..." Dr. Jay Warrior, Agilent Technologies, Chair IEEE 1451.1 WG
- In general, IEEE 1451.1 accomplishes this by providing:
 - Transducer application portability (software reuse)
 - Plug-and-play software capabilities (components)
 - Network independence (network abstraction layer)
- The standard specifies these capabilities by defining software interfaces for:
 - Application functions in the NCAP that interact with the network that are independent of any network
 - Application functions in the NCAP that interact with the transducers that are independent of any specific transducer driver interface



Implementing IEEE 1451.1 in a Wireless Environment

IEEE 1451.1 Overview/Goals (Cont.)



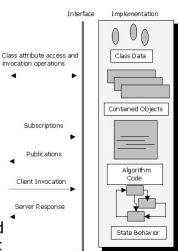
- IEEE 1451.1 software architecture is defined using three different models or views of the transducer device environment:
 - An Object Model, defines transducer device specific abstract objects – or, classes with attributes, methods, and state behavior
 - A Data Model, defines information encoding rules for transmitting information across both local and remote object interfaces
 - A Network Communication Model, supports a client/server and publish/subscribe paradigm for communicating information between NCAPs

Inside an IEEE 1451.1 Object



- IEEE 1451.1 objects look similar to other object-oriented class definitions; they are comprised of instance data, other classes, code for implementing internal operations or methods, and state behavior machines
- Defines services and interfaces required for distributed smart devices (i.e., object discovery, invocation, synchronization) via attribute access and operations
- Specifies Object interfaces and behavior using the Object Model
- The Object Model is formally described using the implementation independent Interface Description Language (IDL)

Implementing IEEE 1451.1 in a Wireless Environment



Types of IEEE 1451.1 Classes

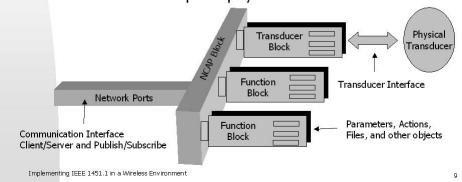


- Four Object classes are found in an IEEE 1451.1 system:
 - ◆ Block Classes (building blocks of the system)
 - * NCAP Block (network communication and configuration)
 - * Function Block (application-specific functionality)
 - * Transducer Block (transducer device driver interface w/app)
 - ◆ Component Classes (common application constructs)
 - * Parameter (contains structured information, network variables)
 - * Action (time-based system state altering activity)
 - * File (supports downloading new code to device)
 - * Component Group (addressing collections of related entities)
 - Service Classes (system and network services)
 - * Client Ports (implements client-side communication endpoint)
 - * Publisher Ports (implements publishing endpoint)
 - * Subscriber Ports (implements subscription endpoint)
 - * Mutex/Condition Service (provides application/NCAP synch)
 - ◆ Non-IEEE 1451.1 Classes

Conceptual View of an IEEE 1451.1 NCAP



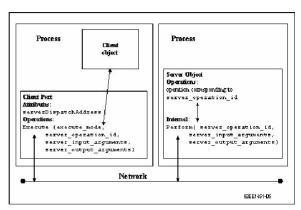
- Uses a "backplane" or "card cage" concept
- NCAP centralizes and "glues" all the system and communications facilities together
- Network communication viewed through the NCAP as ports
- Function block application code is "plugged" in as needed
- Transducer blocks map the physical transducer to the NCAP



IEEE 1451.1 Communication Model



- Provides two styles of inter-NCAP communication
- Client/Server: A tightly coupled, point-topoint model for oneto-one communication scenarios - typically used for configuration, attribute accessors, and operation invocations.

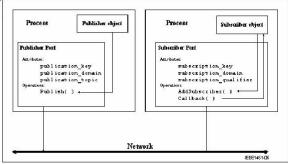


Client objects "Execute()" or invoke operations over the network against a Server NCAP. Server NCAP objects "Perform()" the operation based on the ID and return the results to the clientyronment

IEEE 1451.1 Communication Model (Cont.)



Publish/Subscribe: A loosely coupled, model for many-to-many and one-to-many communication scenarios – typically used for broadcasting or multicasting measurement data and configuration management (i.e., node or NCAP



■ The Publisher is the sending object, it invokes "Publish()" method and does not need to be aware of any receiving objects. Subscribers issue AddSubscriber() method to register interest in something on that subscription.

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discovery) information

Part 2: Implementing IEEE 1451.1



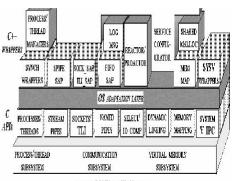
- An IEEE 1451.1 C++ Reference Implementation provides a concrete representation of the abstract Smart Transducer Information Model (IEEE Std 1451.1-1999, Dated 18 April 2000). The NIST implementation is called "1451.1 Lite", as it is a subset of the complete specification.
- A subset of the IEEE 1451.1 implementation has also been developed in Java to provide an architecture neutral NCAP configuration tool.
- The C++ implementation uses the open-source Adaptive Communication Environment (ACE) from the Washington University at St. Louis.

Implementing IEEE 1451.1 in a Wireless Environment

Using ACE Framework for IEEE 1451.1



- ACE is an object-oriented framework for implementing portable real-time communication software patterns in
- All core distribution, concurrency, and communication patterns that underlie the NIST developed IEEE 1451.1 implementation are derived from the ACE library.
- Provides an object-oriented abstraction of operating system services for realtime network and communications support.
- Presently used by major communication companies including: Hughes, Lucent, Ericsson, Siemens, and Boeing among others



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ACE Framework Components



- The Adaptive Communication Environment (ACE) is an object-oriented framework that implements core concurrency and distribution patterns for real-time communication software. ACE includes the following components:
 - * Concurrency and Synchronization
 - * Interprocess communication (IPC)
 - * Memory Management, Timers and Signals
 - ⋆ File System management
 - * Thread Management
 - * Event demultiplexing and handler dispatching
 - * Connection establishment and service initialization
 - * Static and dynamic configuration and reconfiguration of software
 - ⋆ Distributed communication services —naming, logging, time synchronization, event routing and network locking. etc.
- Notice that the ACE components mimic the object requirements found in the IEEE 1451.1 specification; therefore, the mapping was clear but cumbersome because of the specificity of the standard.

Implementing IEEE 1451.1 in a Wireless Environment

Key ACE Architectural Areas Leveraged



- ACE uses well-established object-oriented "patterns", or common design elements, including:
 - ◆ Reactor pattern (efficient event de-multiplexing and dispatching)
 - ◆ Active Object (multi-threaded execution object)
 - Activation Queues (decouples method invocation/execution)
 - Method Objects (queue able objects for execution of commands)
 - ◆ Future Objects (resultant objects of method object execution)
- All of these patterns have concrete representations in ACE, such as ACE Tasks as an Active Object, etc.
- The low-level C++ TCP/IP socket "wrapper" routines were not used because this would mitigate using the advanced features of the object-oriented framework

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Key ACE Architectural Areas Leveraged



- IEEE 1451.1 "Entity" class forms the base class for all network and block services in the standard. The "Entity" class inherits the ACE "service handler" class, which integrates event-driven "Active" object patterns with TCP/IP communication endpoints and synchronization.
- ACE "service handler" interface supports real-time eventdriven input/output on multicast/unicast TCP/IP sockets, providing an efficient networking scheme.
- The IEEE 1451.1 standard specifies a data encoding sequence for passing parameters between objects. An on-the-wire network-based data representation for marshaling these parameters is required for each control network used. For TCP/IP networks, NIST used a CORBA compliant implementation of the Common Data Representation (CDR) library found in ACE.

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Key ACE Architectural Areas Leveraged



- Internally, the NIST IEEE 1451.1 code uses the CDR base types as well. This reduces the amount of encoding and marshaling overhead needed from converting base types to the CDR types during marshaling activities.
- Blocks and Ports use ACE

 "Tasks" for their

 multithreaded state

 machine behavior. Each

 Block/Port class

 implementation provides

 a virtualized svc() routine

 to support each blocks

 defined state machine.

 | Metal state and include the state and include the

```
while (1)

// get current state of inderlying Block
ret - IEEE1451 Dlock: GetFlockHojorState(bas):
switch (bas):

case FLUNKTIALIED: break;
ret - IEEE1451 FauntionFlock, GetFunc.incBlockState(flay),
// eater to thick substate state machine
switch (bb)

(case FLUNKTIALIED: break;
case FLUNKTIALIED: break;
break;
case FLUNKTIALIED: break;
case FLUNKTIALIED: break;
cetault break
cetault break
```

Implementing IEEE 1451.1 in a Wireless Environment

Progress to Date



- Majority of the design in place (using inheritance and composition of ACE services with 1451.1 code base)
- 70-75% of IEEE 1451.1 C++ code complete, all IEEE 1451.1 methods have placeholders, network encoding still under development
- Core subset (.1 Lite) nearly complete, consists of a shared library under Linux/FreeBSD & VxWorks and a dynamic link library (DLL) under WIN32/NT
- Because the ACE framework is being used, a single source code-base that is 100% portable to Linux/FreeBSD, NT, VxWorks, and other POSIX or WIN32-based operating systems has been developed
- At this time, there is minimal access to the underlying STIM or microprocessor hardware via device drivers, (most I/O such as temperature, pressure, or actuator data has been provided by the NCAP via simulation)
- Java implementation consist of most blocks and communication ports.
 A CDR encoding from the Zen Project at University of California, Irvine has been integrated and is interoperable with C++ version.

Implementing IEEE 1451.1 in a Wireless Environment



Lessons Learned on Implementation

- The standards' low-level attempt to redefine the RPC (Remote Procedure Call) mechanisms for network communication preclude and limit the implementer's ability to optimize the amount and types of communication patterns that can be used in normal real-time object-oriented network communication software design.
- Many object-oriented patterns are disallowed because of arbitrary inheritance chain and class partitioning.
- Partitioning forces the designers and implementers of the software to create overloaded and convoluted classes in order to pigeon hole the standard into certain middleware and object-oriented frameworks.

Implementing IEEE 1451.1 in a Wireless Environment

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Lessons Learned on Implementation

- Large number of deployed NCAPs could be problematic for system configuration, initialization, and maintenance unless highly sophisticated configuration tools are developed.
 However, software vendors can provide those tools.
- Modern middleware provides similar service-oriented class characteristics; an OS adaptation layer standard definition approach would ease integrating application functionality.

Implementing IEEE 1451.1 in a Wireless Environment

Lessons Learned on Implementation



- The backward or legacy approach to preserving other device bus application interaction complicates and makes the standard over specify itself.
- Implementations of the standard (in C++) are cumbersome and very large for many small embedded systems. A subset standard (IEEE 1451.1 Lite) should be considered for the applications that only need a small subset of the current 1451.1 standard specification.
- NIST implementations unique use of CDR streams as the underlying data typing mechanism provides a less complex asynchronous and synchronous communication marshaling routines.

Implementing IEEE 1451.1 in a Wireless Environment

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IEEE 1451.1 Benefits

- Using P1451.1 provides:
 - an extensible object-oriented model for smart transducer application development and deployment
 - application portability achieved through agreed upon application programming interfaces (API)
 - network neutral interface allows the same application to be plug-and-play across multiple network technologies
 - leverages existing networking technology, does not reimplement any control network software or protocols
 - a common software interface to transducer hardware i/o

Implementing IEEE 1451.1 in a Wireless Environment



Part 3: Looking at an IEEE 1451.1 Application

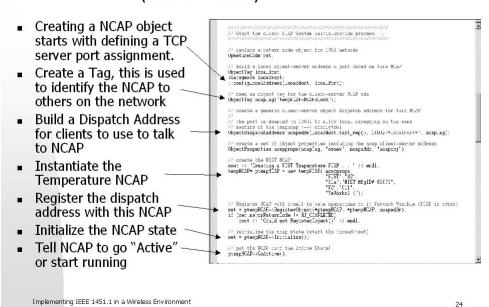
- A minimal IEEE 1451.1 application consist of a few classes:
 - An NCAP Block (consolidates system and communication housekeeping)
 - ◆ A Transducer Block (provides the software connection to the transducer device)
 - ◆ A Function Block (provides the transducer application algorithm (i.e., obtain and multicast temperature data every second)
 - Parameters (contains the network accessible variables that hold and update the data)
 - Ports (network communication objects for publishing and subscribing to information or interacting with other NCAPs using client/server

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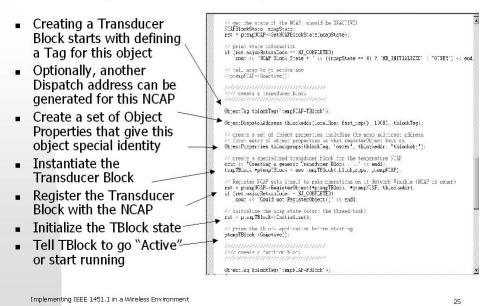
A C++ IEEE 1451.1 Application (NCAP Block)





A C++ IEEE 1451.1 Application (Transducer Block)





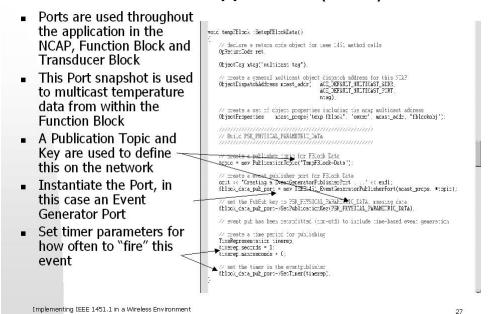
A C++ IEEE 1451.1 Application (Function Block)



Creating a Function Block starts with defining a Tag for this object ObjectTag fblockTag('tempMCaP-FBlock'): Optionally, another Dispatch ObjectDispatchiddress fblocklddr(localEnst fast_rep(), 10005, fblockTag): address can be generated for mans a set of object properties including the user subjects address or instrements of cased parties is what registerObject keys on ... ObjectParperties filoiAprops(filoiATeg. 'owner', (blockAddr. 'filoiAbbj'). this NCAP / oreats a generic function block for the application out ('Creatine's Publisher Function Eloix ...' (endl.) enpFEloix =prexpFEloix = new tempFEloix(fbloixprops, ptempTEloix) Create a set of Object Properties that give this /texpFBlock ptexpFBlock(fblockprope, ptexpTBlock): object special identity // Degister the FClock to raise operations on it Mercock Visible (PCAP block is swear) ret = prospNCAP-SegisterObject(pricepFlock, =pterpSCAP, (blockAdr); if (pet.majrpscFfloce = SCOFFEETO) correction trild not MegisterObject()? << edi. Instantiate the Function Block initialize the most state (start the thread/task)
ret_s n=spERInck-Virtualize(); Register the Function Block // prime the fblock application before starting prempfDlock-9Gactive(): with the NCAP Initialize the Function Block // now actually start the application
prempFBlock->Start(): // get ale state of the NCAF again, should be ACTIVE! ret prempNCAF->GetMCAPElookStatm(moapEtate) Tell Transducer Block to go "Active" // grant costs information
if (set.majorPeterplodo - M_COMPLETED)
cons < 'KEM' Block State - ' < ((seepState - 4) ? 'MD_BUTTALISED' : 'OTBER') < sad Manually "Start()" the // pricess sweats in the lese shylroment MCas_UA1._ON_EVEX.S application or do it later from a network invocation Implementing IEEE 1451.1 in a Wireless Environment 26

A C++ IEEE 1451.1 Application (Ports)

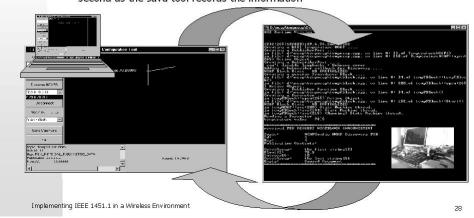




Executing an IEEE 1451.1 Application



- An embedded Temperature NCAP Application is running from a remote location on the NIST Intranet
 - As part of the system configuration, a NIST developed Java tool on a Notebook issues a discovery multicast, finds the NCAP, and starts the remote NCAP's Function Block
 - The remote NCAP Function Block responds by publishing temperature data every second as the Java tool records the information



Part 4: Using IEEE 1451.1 in a Wireless Environment

- NIST CENTENNIAL
- The NIST C++ IEEE 1451.1 reference implementation uses TCP/IP as its underlying control network.
- From TCP/IP, IP multicast and TCP unicast features are used to implement publish/subscribe and client/server, respectively
- ACE is used to abstract the networking code from the application; therefore it is highly adaptive to various protocols
- Wired 802.3 Ethernet has been used primarily for testing. No changes were needed in ACE to support this protocol.
- Wireless 802.11b (11Mbps) Ethernet has also been used for testing. Again, no changes were made to ACE as the TCP/IP protocol is compatible with both 802.3 and 802.11b physical mediums.

Implementing IEEE 1451.1 in a Wireless Environment

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Using IEEE 1451.1 in a Wireless Environment



- Testing scenarios included using a wired subnet connected to a wireless extension of the subnet
- Wireless extension uses an Agere (formerly Lucent) Orinoco AP-1000 dual card "access point"
- Range extender antennas are also connected to the access point and each PC-CARD
- Each node on the wireless side executes an IEEE 1451.1 NCAP application
- Java Configuration tool executes beyond the wireless net on the wired subnet

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- Бевікор Совідшев

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Using IEEE 1451.1 in a Wireless Environment



- Limited testing scenarios confined to the office environment at NIST
- Experience has not been good due to range problems within our building.
- Structural barriers within the walls severely restrict the range available from NCAP to access point
- Building constructed in the 60's of solid concrete block with concrete floors, offices
- Range using a wireless subnet is no greater than 20-25' with antenna
- High-end of 11 Mbps range only reached with 15'
- All applications worked as advertised albeit with limited range.
- Multicasting through the bridge needed to be configured through the access point
- Noticeable delay for multicast depending on how configured at access point

Implementing IEEE 1451.1 in a Wireless Environment

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Summary



- IEEE 1451.1 is a comprehensive and large standard that adequately addresses the smart transducer industry need for portability and network independent access.
- The standard however in addressing all the facets of the smart transducer is complex and quite large.
- NIST has embarked on implementing a good deal of the standard with emphasis on getting the communication and infrastructure code in place in order to start using the code.
- Choosing and implementing the standard with a solid object-oriented framework such as ACE provides a robust environment for real-time network communication.
- Migrating the implementation to other middleware such as CORBA for heavier weight uses will be reasonable to do
- Several projects at NIST will use the implementation for supporting manufacturing related activities

Implementing IEEE 1451.1 in a Wireless Environment

Summary (cont)



- Continued testing in the wireless space is required to gauge the effectiveness of the implementation.
- Bluetooth trials are forthcoming; however, the lack of multicast support will severely impact the applications – continued research here is a must
- Other lightweight middleware packages are going to be isolated – XML and SOAP, etc; however, these protocols do not support asynchronous messaging or publish subscribe in efficient ways
- Slimmer implementations of the IEEE 1451.1 will need to be experimented with for use with the smaller micro platforms.

Implementing IEEE 1451.1 in a Wireless Environment

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References



- More information about ACE can be found at: www.cs.wustl.edu/~schmidt/ACE.html
- IEEE 1451.1-1999 Standard for a Smart
 Transducer Interface for Sensors and
 Actuators Network Capable Application
 Processor Information Model 2000, ISBN 0-7381-1768-4

Implementing IEEE 1451.1 in a Wireless Environment

3.3 Bluetooth: Small Sensor Area Networks (SANs)

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Bluetooth

Small Sensor Area Networks (SANs)

Thurston Brooks

with contributions by Ericsson Mobile Communications AB

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Wireless Advantages

- Augment wired LANS
- Minimize setup requirements by installing preconfigured WLANs without MIS support
- · Factory floor can exchange data with central databases
- · "Instant" reconfigurability
- · Installation simplicity and flexibility
- Cost effective TOC
- Mobility-WLANs can provide access to real-time info on-the-go
- Scalability

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Wireless Advantages (Cont.)

- Eliminates logging and paperwork
- · Historical data is easily maintained
- · Reduces data gathering errors

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Wireless Condition Monitoring

- · Will reduce monitoring installation cost
 - \$20/ft typical, as much as \$2000/ft some apps (e.g., Nuclear)
 - Cabling is 30-45% of TOC
- Real-time dynamic range is expensive (correlates to difficulty)
- Spread spectrum technology with data dumps is now feasible for low cost
- Portable
- Immediate alert of alarm conditions and follow-up data dumps are also feasible

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Manufacturing Solutions

- Majority of wireless products in marketplace are proprietary spread spectrum and narrow band solutions in the ISM bands (400MHz, 900MHz, 2.4GHz)
 - Today 80% of customers → SS (*Garner Group)
- Typically constrain user to buy from a particular vendor
- Interoperability, low-cost, and broad user base (i.e., market demand) are stimulated by Standards

IEEE 802.11 (2.4GHz @1-2Mbps)
 Bluetooth (2.4GHz @ .75Mbps)
 PAN

• Potential Interference between 802.11 and Bluetooth

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Narrowband Manufacturing Solutions

- Available since early 1980s
- Low throughput
 - term NB → RF BW typically 12.5-25.0 kHz
- Longest Range
- Low cost for large sites
- Little or no vendor interoperability
- · Easily jammed
- Site license required for protected bands (450-470 MHz)
- · Large form factor

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900 MHz ISM Manufacturing Solutions

- Here Today many 900 MHz LANs in use
- Data rates of 100-450 Kbps are sufficient for many manufacturing applications
- Typically better range than 2.4 GHz systems
- Very crowded band
 - US: cordless phones, vehicle locators, etc.
 - International: GSM cellular and military systems
- Little interoperability
- · Lack international acceptance

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2.4 GHz ISM Manufacturing Solutions

- Standards based systems
- Multi-vendor support
- · High data rates available
 - IEEE 802.11 10 Mbps- Bluetooth 1 Mbps
 - World-wide acceptance
- · Limited range
 - Attenuation
 - Less power
 - Poor coverage Increased infrastructure costs

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IEEE 802.11b

- Defines wireless LAN interoperability
- Two forms:
 - Frequency Hopping Spread Spectrum (FHSS)
 - · 2.4 GHz 79 Channels 1 MHz wide (US)
 - Direct Sequence Spread Spectrum (DSSS)
 - 2.4 GHz 3 non-overlapping Channels 22 MHz wide (US)
 - · 2.4 GHz 1 Channel 22 MHz wide (Japan)
- Both techniques limited to 1W max radiated power US

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802.11 and Bluetooth Interference Potential

- · Both standards use frequency hopping
- Bluetooth is predicted to "jam" 802.11 FHSS operation
 - BT will most likely interrupt an 802.11 transmission many times before the 802.11 device hops to the next frequency (Jim Geier-Wireless Nets)
- · FCC does not mediate frequency conflicts in the unlicensed bands
 - IEEE has created the 802.15 Coexistence Task Group 2
- Preliminary analysis by 802.15 Group indicates that 802.11 DSSS is very reliable in the presence of BT
- Solutions
 - BT falls off quickly, avoid close proximity with 802.11 devices
 - Reduce 802.11 radio distance

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Advantages of Spread Spectrum

- SS can co-exist with other systems that are already using the same frequency bands
- SS has excellent discrimination of signals in multipath environments
- SS is less interference prone that other techniques particularly in manufacturing environments where "noise" can be severe
- · SS in the ISM Bands do not need licensing
- · SS combined with TDMA has nearly unlimited capacity

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Data Rates Manufacturing Solutions

| Frequency | Data rate |
|-----------------------|---------------|
| 400 MHz UHF NB | 4.8-19.2 Kbps |
| 900 MHz SS | 100-400 Kbps |
| 2.4 GHz SS | 1-2 Mbps |
| 2.4 GHz SS (802.11b+) | 10 Mbps+ |
| 5.7 GHz (Future) | 20 Mbps++ |

Guide to Wireless LAN Technologies, Intermec Tech Corp

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Ranges of RF Manufacturing Solutions

| Frequency | Indoor Range |
|--|--------------|
| 400 MHz UHF | 300-400 ft. |
| 900 MHz SS | 220-350 ft. |
| 2.4 GHz SS 100mW US, Asia, Pacific, Latin America | 150-200 ft. |
| 2.4 GHz SS 500mW US, Asia, Pacific, Latin America | 200-250 ft. |
| 2.4 GHz SS 100mW Europe | 125-150 ft. |

Guide to Wireless LAN Technologies, Intermed Tech Corp

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Factors Effecting Range

Transmitter Power

 The FCC regulations permit radiated RF power for unlicensed operation of up to 1 watt (+30dBm) when spread spectrum modulation techniques are used. All ISM band wireless modem and wireless LAN products must adhere to these requirements.

Receive Sensitivity

 Receiver sensitivity quantifies the ability of a receiver to respond to weak signal levels. Typically stated as Maximum Bit Error Rate at a certain RF level, e.g., 10⁻⁶ BER @ -70dBm

Path Loss

- Signal attenuation between the transmitter and the receiver.

Antenna Gain

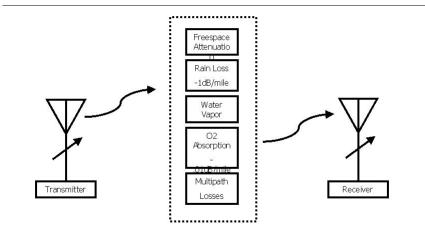
- Apparent increase in signal strength due to beam forming.

Slide Courtesy of Robert Haller, Grayhill

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Wireless Attenuation

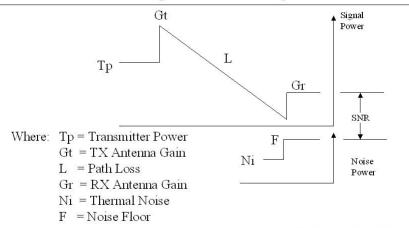


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Range - Link Budget



Slide Courtesy of Robert Haller, Grayhill

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Antenna Fundamentals

• Omnidirectional (Isotropic Source)

- An isotropic source is a source radiating energy equally in all directions.

Directivity

 Directivity is the ratio between the maximum radiation intensity from a transmitter and the radiation intensity from an isotropic source radiating the same power.

Gain

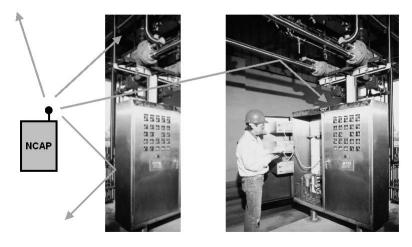
 The gain of an antenna is a function of the antenna's directivity – as the antenna's beam is focused it's Effective Radiated Power (ERP) is increased.

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Multipath



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Ray Tracing

- Software modeling of 2D or 3D ray tracing is the most reliable.
- System using only free-space path loss are the least reliable
- Modeling has limited value within a manufacturing plant

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Applications

· Retail

- Wireless link to database
- Transaction based
- Inventory control

Warehouses

- Handheld devices improve efficiency
- Eliminate paper
- USPS logs trucks in and out of distribution centers

· Healthcare

- Patient monitoring
- Tracking pharmaceuticals

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Applications (Cont.)

- Restaurants
- Utilities
 - Meter reading
 - · Handheld devices improve efficiency
 - · Eliminates paper
 - Kansas City Power & Light system monitors 150,000 customers, automatically tracks usage and issues bills – no meter readers
 - Monitor electrical distribution
- Vending
 - Typically utilize existing cellular networks

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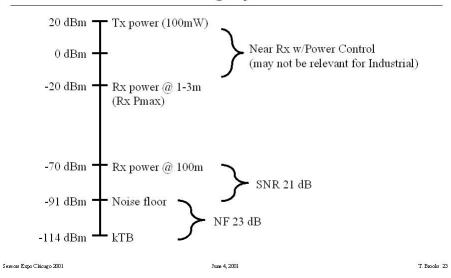
Applications (Cont.)

- · Traffic Monitoring
- Industrial Process Plants
 - Tank Farms
 - · Monitor fluid levels, flow rates, temperatures
 - LOS 2 miles
- Ship/Transportation Crane Controls (Omnex)
- · Manufacturing Cells

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Bluetooth Link Budget for Max Power TX



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Operational States

- Standby
- · Inquiry-Paging
- · Connections
 - Active
 - Power Conserving
 - Hold (delta t)
 - Sniff (Poling)
 - · Park (Listen but do not disturb master)
- Synchronous Connection-Oriented (SCO) Link (primarily used for voice)
- Asynchronous Connection-Less (ACL) Link (primarily used for packet data)

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Features

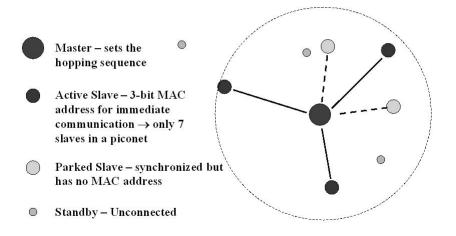
- · Regulations
 - FCC Part 15 compliance
 - ETSI 300 328
- Frequencies
 - covers all of the 2.4GHz ISM band
- Time Division Duplex
- · Stand-by Modes
 - Park
 - Hold
 - Sniff
 - Standby

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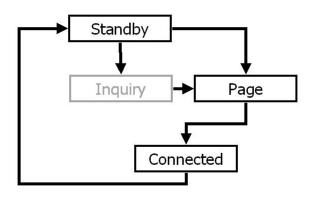
Operational States



Sensos Expo Chicago 2001 June 4, 2001 T. Brooks 26

3_e Technologies International,

Making a Connection

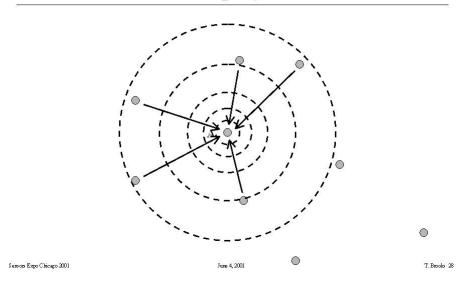


Sensor Expo Chicago 2001 June 4, 2001 T. Brooks 27

Sensors Expo 2001 - Bluetooth Small SANs

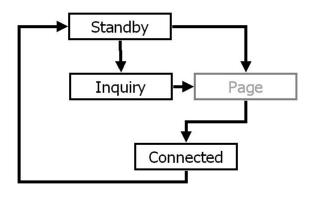
3_e Technologies International, Inc.

Inquiry



3_e Technologies International,

Making a Connection

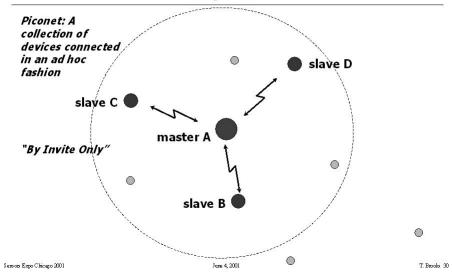


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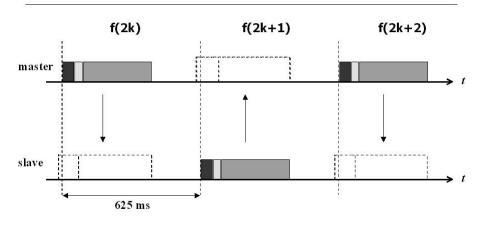
3_e Technologies International,

Creating a Piconet



3_e Technologies International,

FH with TDD Channel

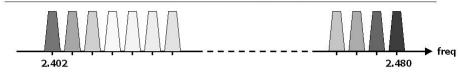


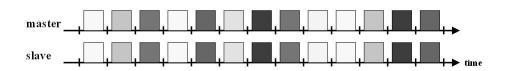
Sensor Expo Chicago 2001 June 4, 2001 T. Brooks 31

Sensors Expo 2001 - Bluetooth Small SANs

3_e Technologies International, Inc.

Frequency Hopping

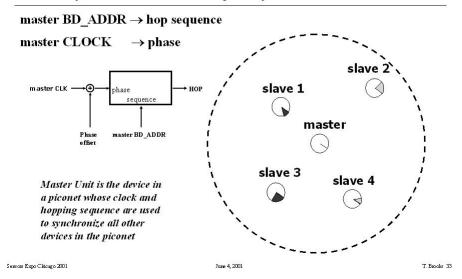




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 T. Brooks 32

3_e Technologies International,

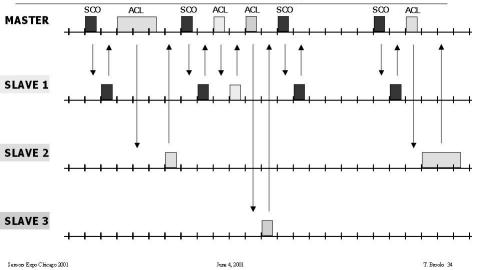
Synchronisation of Physical Channel



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3_e Technologies International,

Mixed Link Example



3_e Technologies International,

Data Rates (kb/s)

| type | symmetric | asymmetric | |
|------|-----------|------------|-------|
| DM1 | 108.8 | 108.8 | 108.8 |
| DH1 | 172.8 | 172.8 | 172.8 |
| DM3 | 258.1 | 387.2 | 54.4 |
| DH3 | 390.4 | 585.6 | 86.4 |
| DM5 | 286.7 | 477.8 | 36.3 |
| DH5 | 433.9 | 723.2 | 57.6 |

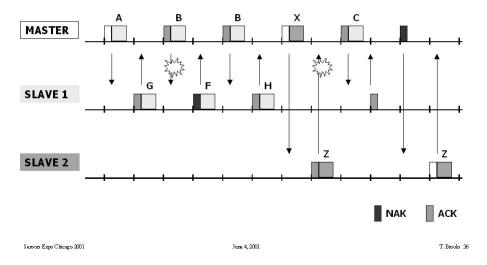
Master unit controls the link bandwidth, decides how much is given to each slave, and sets the symmetry of the link

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Sensors Expo 2001 - Bluetooth Small SANs

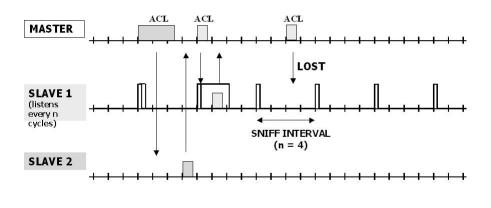
3_e Technologies International,

Automatic Repeat Request (ARQ) Scheme



3_e Technologies International,

Sniff Mode

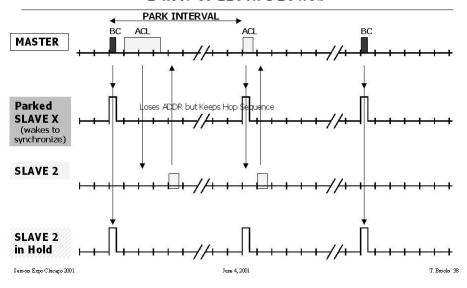


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Sensors Expo 2001 - Bluetooth Small SANs

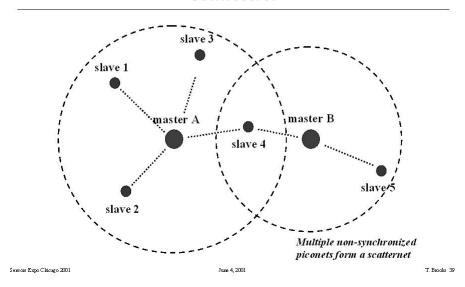
3_e Technologies International,

Park & Hold Modes



3_e Technologies International,

Scatternet



Sensors Expo 2001 - Bluetooth Small SANs

3_e Technologies International, Inc.

Bluetooth Today (242 products)



3_e Technologies International, Inc.

Information

- http://www.bluetooth.com
- http://news.zdnet.co.uk/0,,t294,00.html
- Any Search on "bluetooth"

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3.4 Wireless Ethernet (802.11) Overview



Wireless Ethernet (802.11) Overview

James D. Gilsinn

National Institute of Standards & Technology Intelligent Systems Division james.gilsinn@nist.gov

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Slide 1



What is IEEE 802.11?

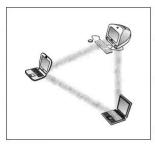
- IEEE 802.11 is extension of Ethernet standard (IEEE 802.3) into wireless communications
- Allows roaming computers to talk to other devices (peer-to-peer) or connect to wired network (transmitter/receiver)
- IEEE standard allows interoperability between multiple vendors products

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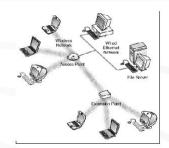
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Examples of 802.11 Networks



Peer-to-Peer Network



Transmitter/Receiver (Wired/Wireless Network)

Pictures from Vicomsoft Web Site, http://www.vicomsoft.com/

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Slide 3



802.11 Specification

- Speeds of 1-2 Mb/sec
- Operating Range: 10-100m indoors, 300m outdoors
- Power Output Limited to 1 Watt in U.S.
- Frequency Hopping (FHSS), Direct Sequence (DSSS), & Infrared (IrDA)
 - Networks are NOT compatible with each other
- Uses unlicensed 2.4 GHz band (2.402-2.480 GHz)
- Provide wireless Ethernet for wired networks

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802.11 Variations

- 802.11a
 - Speeds of 6-54 Mb/sec
 - Uses 5 GHz band instead
 - Not commercially available, at the moment
- 802.11b
 - Speeds of 5.5 or 11 Mb/sec
 - Direct Sequence Spread Spectrum (DSSS) Only
 - Backward compatible with 802.11 DSSS components

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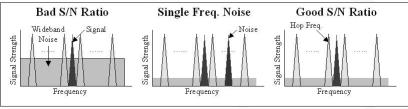
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Slide 5



Freq. Hopping Spread Spectrum

- Uses 79 separate 1 MHz channels from 2.402-2.480 GHz
- Hops about every 0.1 sec (22 hop pattern, 2.5 hop/sec minimum in US)
- Immune to single frequency noise, has trouble with wideband noise
- Many networks can be located in the same area
- Uses less power to transmit & less expensive to build than DSSS

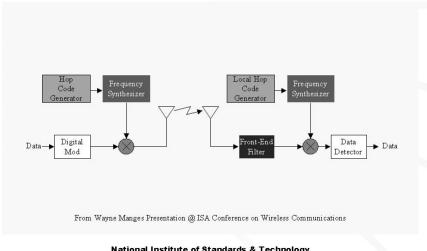


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FHSS Block Diagram



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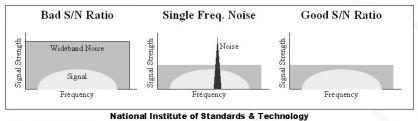
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Slide 7



Direct-Sequence Spread Spectrum

- Signal modulated with a spreading code (11-bit Barker Sequence)
- · All 802.11b compliant products use the same spreading code
- Higher data rates because of "fatter pipe" (about 11 MHz)
- Allows for some single frequency noise & higher wideband noise
- · Only allows for 3 networks in same area
- Uses higher power to transmit & more expensive to build than FHSS



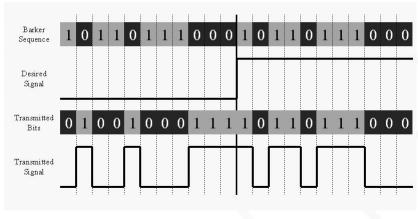
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DSSS (cont'd)

Transmit data bits 01 using DSSS spreading code 10110111000



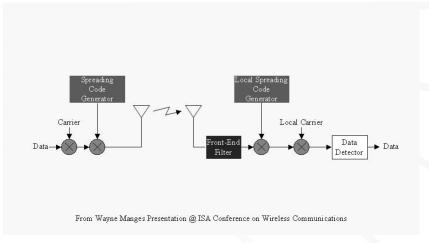
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Slide 9



DSSS Block Diagram



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802.11b Security (WEP Protocol)

- 802.11b uses Wired Equivalent Privacy (WEP) protocol for encryption and authentication
- WEP protocol is self-synchronizing
- 64-bit key (40-bit secret code, 24-bit "init" vector)
 - 128-bit keys available for extra \$\$\$
- Additional info sent with message for data integrity checks (i.e. CRC-32)
- · Uses same key to encrypt/decrypt message

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Slide 11



802.11b Equipment

- IEEE standard allows for many vendors
 - Access Point Base Stations \$200-\$1200

Access Point Software \$175

- PCMCIA Cards \$80-\$375

- PCI Cards \$50-\$300

- Extension Point Base Stations \$1400
- Prices vary greatly due to different features like security options, number of users, etc.
- http://www.wirelesscentral.net/

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References

- http://www.cwt.vt.edu/
- http://www.unc.edu/depts/oit/ns/wireless/
- http://www.vicomsoft.com/
- http://www.wirelessethernet.org/
- http://www.wlana.com/
- http://www.wirelesscentral.net/
- http://www.nortelnetworks.com/
- http://www.proxim.com/
- http://www.cisco.com/

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3.5 Wireless Interface Options for 1451

Wireless Interface Options for 1451

Presented at the Wireless Sensing Workshop Sensors Expo /2001 June 4, 2001

Michael R. Moore Oak Ridge National Laboratory

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Key Elements of Sensor Standard

- TEDS
- Synchronization of Data Sampling
- Unique Identification
- Accessibility to Networks (e.g. Internet)
- Plug-and-Play Sensor Connections

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Business And Technology Issues Drive Selection

- Business/Marketing
 - Industry Acceptance
 - » Cost
 - » Availability
 - » Reputation
 - » Form and Function
 - Standards Development
 - » Leverage Current Standards
 - » Buy-in From Membership
 - Future Growth

- Technology
 - Bandwidth
 - Power requirements
 - Compatibility
 - » System Integration
 - » RF Interference
 - # of Nodes
 - Size/Length of Network
 - Extensible for Future Growth

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Candidate 1451 MAC/PHY From Other Wireless Standards

(Business Issues)

- Use IEEE 802 Family As a Model
 - Get Market Acceptance of Protocol
 - Let MAC/PHY Adapt to the Market Place
- Time to Market
 - Which MAC/PHY Are Supported by Current ASICs
 - Which Existing Standardized PHY is the Closest to Meet Our Needs
- Cost

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Candidate 1451 MAC/PHY From Other Wireless Standards

(Technology Issues)

| Std | OFDM | FHSS | DSSS | GHz | Size | Mbps |
|-----------|------|------|------|-------|------|---------|
| IS-95 | | | X | 1 +/- | Cell | 0.x |
| Bluetooth | | X | | 2.45 | PAN | 1 |
| P802.15 | | X | | 2.45 | PAN | 1 |
| P802.16b | X | | | 5 | WAN | 54 |
| 802.11a | X | | | 5 | LAN | 54 |
| 802.11 | | X | X | 2.45 | LAN | 1, 2 |
| 802.11b | | | X | 2.45 | LAN | 5.5, 11 |

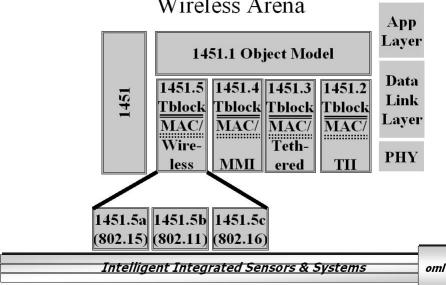
Intelligent Integrated Sensors & Systems

IEEE 802 Wireless Projects

- IEEE 802.15 (Bluetooth)
- IEEE 802.11
 - » Clause 14 1,2 Mbps FHSS LAN MAC for 2.4 GHz
 - » Clause 15 1,2 Mbps DSSS LAN for 2.4 GHz
 - IEEE 802.11a
 - » Adds Clause 17 ≤54 Mbps OFDM LAN for 5 GHz
 - IEEE 802.11b
 - » Adds Clause 18 5.5 and 11 Mbps DSSS for 2.4 GHz
- IEEE 802.16b (task group 4) Wireless High-Speed Unlicensed Metropolitan Area Network (Wireless HUMAN)
 - » MAC: IEEE 802.16
 - » PHY: IEEE 802.11a; ETSI BRAN HIPERLAN/2

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IEEE P1451.5 Could Accommodate Rapidly Changing Wireless Arena

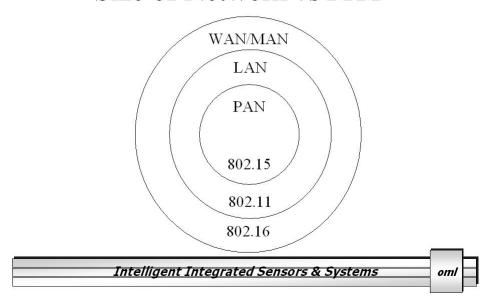


1451.5 Wireless Leverages Other 1451 Projects

- Smart Transducer Object Model from 1451.1
- TEDS Concept from 1451.2
- Synch and XML TEDS from P1451.3
- Compact TEDS and Transducer Interface from P1451.4



Size of Network vs PHY



Future Growth

- A Well-Planned Architecture Enables the Quick Incorporation of...
 - Emerging Wireless Technologies
 - Security (as described in IEEE 1363)
 - Mobile Ad-Hoc Networking
 - Others



Conclusion

- A new Wireless Interface, IEEE P1451.5, is Proposed that will
 - Leverage Sensor Networking Capabilities From the Other IEEE 1451 Projects
 - Include Multiple MAC/PHY Combinations
 - Use IEEE 802 Approach as a Model
 - Has a Layered Architecture
 - » Enables Rapid Ramp-Up Utilizing Existing Products
 - » Enables Future Growth

Intelligent Integrated Sensors & Systems

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3.6 Developing Executable Specifications for Networking Smart Transducers to Bluetooth

Developing Executable
Specifications for Networking
Smart Transducers to
Bluetooth

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Information Electronics
The Ohio State University
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15 May 2001

Department of Electrical Engineering



ectronics

Problem Statement

Problem Statement

- Networking smart transducers wirelessly is attractive
- For small-span networks, using existing wireless technology is simpler, quicker and inexpensive
- Challenge is to design a network infrastructure according to voluminous, complicated standards and new commercial technology





Wireless Sensor Standards

- Combining Sensor Standards with Wireless Standards is error prone. Key requirements are nebulous --- battery life?
- Need to be able to exercise & forecast how the specifications will play out:
 -System Level Definition Language www.sldl.org (get white paper)
- Hardware Description Language (VHDL)



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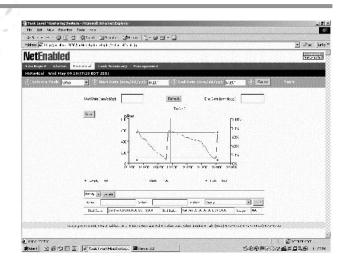
NetEnabled Overview

- Connecting Devices to:
 - Networks
 - Data centers
 - Desktops
- Using
 - Serial, Ethernet, RF, TCP/IP, cellular, CDPD, satellite, pager
- Need:
 - RF technologies supporting:
 - 4+ years for hourly readings using only 3.6V, 5000mAhr battery
 - Variable transmissions power and distance
 - Fast sync times and short protocol negotiations
 - Application: Class I, Div I environments





MyTankLevels.com





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ASIC+

- Electronics Design Business
- Specialty in Mixed Signal ASIC tapeouts.
- RF CMOS chip design and delivery.
- Embedded Systems and Firmware.
- Strong Methodology in using Hardware
 Description Languages mainly for
 digital systems but also for Analog
- IEEE 1076 (1987, '93, '99) VHDL-AMS

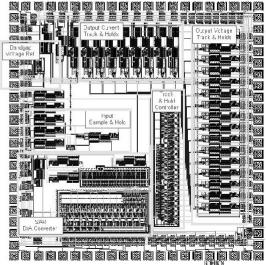




Past Designs and Customers

- System (SoC)
- RF Sensor Codec
- Satellite Control
- RF ID Tag
- UWB
- contact:
- Todd James

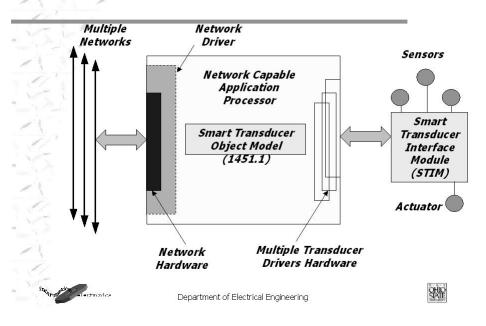




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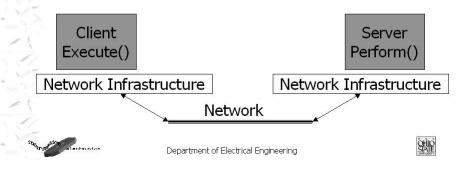
Background

IEEE 1451.1 Standard

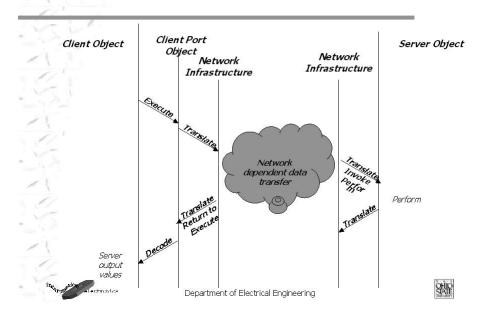


IEEE 1451.1 Client-Server Network Model

- Tightly coupled, point-to-point model
- NetInf translates IEEE 1451 datums to network specific format



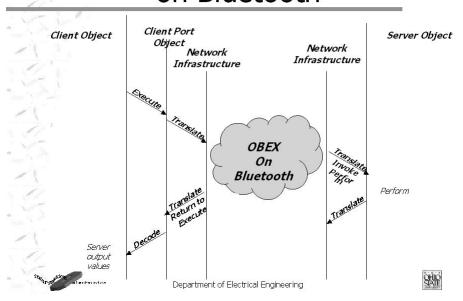
IEEE 1451 Client-Server Model



Problem

Statement

IEEE 1451 Communication on Bluetooth

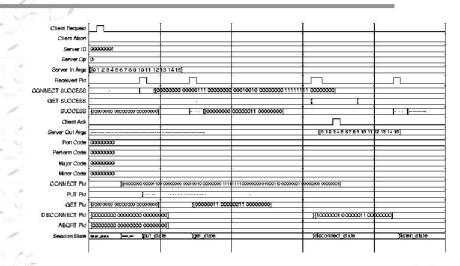


VHDL Design of Interface Entity

Problem Statement

Problem Statement

Example VHDL Simulation



inguida electronics

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Methodology

- Design the requirements of a network infrastructure.
 - Detailed study of IEEE 1451 standard
 - Evaluation of existing wireless technology examination of Bluetooth
 - Detailed study of a session protocol, OBEX
 - How should IEEE 1451 transducers communicate on OBEX?
- Develop a VHDL software model of system.
 - Behavioral description of client-side functionality.
 - Simulations





Example of a Smart Transducer Network

Background

- Remotely monitored UAV (Unmanned Aerial Vehicle)
- Applications
 - Military surveillance and law enforcement
 - Environment monitoring and pollution control
 - Media coverage

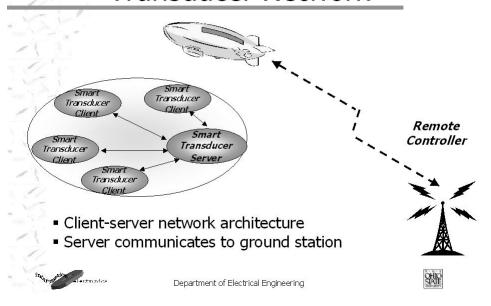


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Example of a Smart Transducer Network

Background



Wireless Flying Sensor Platform

■ In the lab and then at the videoconference.





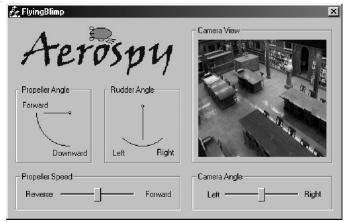


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User Interface



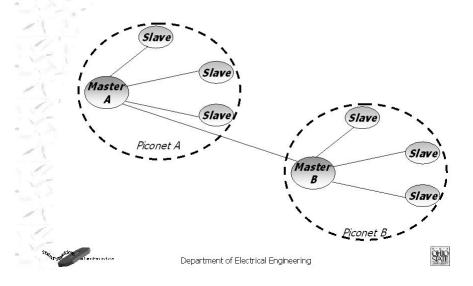




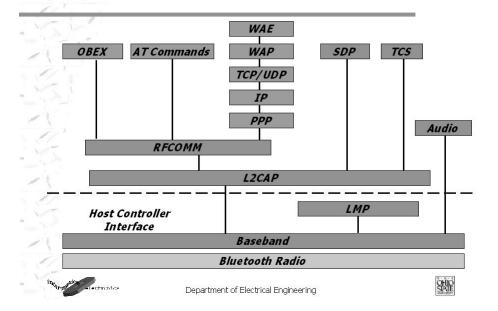


Bluetooth Network Architecture

Background



Bluetooth Protocol Stack



Protocol for interfacing Bluetooth with IEEE 1451

Background

- IEEE 1451 Client nodes "Execute" the "Perform" operation on Server nodes
- Session-level protocol required for client server communication
- Two options
 - TCP/IP Large overheads
 - OBEX Light version of HTTP
- OBEX is the chosen alternative



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Background

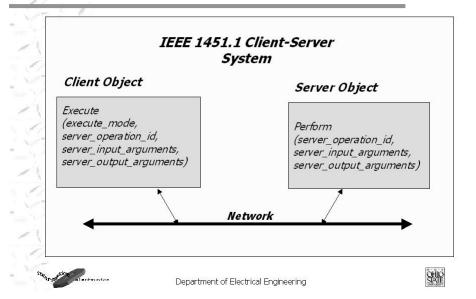
OBEX Protocol

- Primarily developed by IrDA and adopted by Bluetooth for interoperability
- Example applications are for short-range business card exchange or synchronization
- Can operate on both RFCOMM as well as TCP/IP as transport
- Defined by
 - OBEX Object Model
 - OBEX Session Protocol



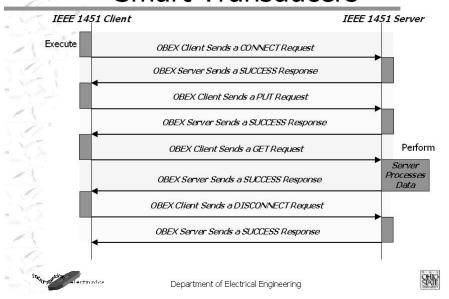


IEEE 1451 Communication on Bluetooth

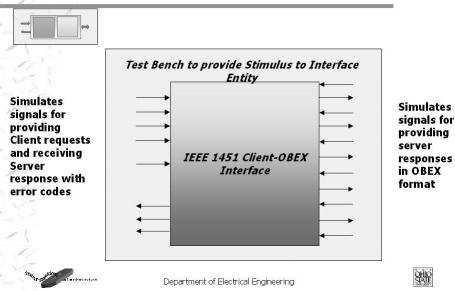


OBEX Session Protocol for Smart Transducers

Design



Test Bench for Design



VHDL Design of Interface **Entity**

Design

```
ENTITY interface IS
          client_request : IN BIT;
client_abort : IN BIT;
serverid : IN UInteger8;
           server_operation: IN INTEGER;
        server_operation : IN INTEGER;
server_input_args : IN integer_array;
received_ptt : IN BIT;
connect_success_pkt : IN byte_array(0 TO 6);
get_success_pkt : IN byte_array(0 TO payload_packet_length);
success_pkt : IN byte_array(0 TO 2);
client_ack : OUT BIT;
server_output_args : OUT integer_array;
portcode : OUT UInteger8;
performcode : OUT UInteger8;
majorcode : OUT UInteger8;
minorcode : OUT UInteger8;
connect pkt : OUT byte array(0 TO 10);
         rminotode: OUT byte_array(0 TO 10);
put_pkt: OUT byte_array(0 TO payload_packet_length);
get_pkt: OUT byte_array(0 TO 2);
disconnect_pkt: OUT byte_array(0 TO 2);
abort_pkt: OUT byte_array(0 TO 2);
session_state: OUT state);
END interface;
```



VHDL Design of OBEX Session

```
ENTITY obex_session IS
 PORT(check: IN BIT; -- clock for session protocol
     client_abort : IN BIT; -- client node aborts operation
     server_id : IN UInteger8;
    obex_body_object : IN obex_body;
obex_send : IN BIT;
    obex_receive : IN BIT;
     connect_success_pkt : IN byte_array(0 TO 6); -- success to connect
     get_success_pkt : IN byte_array(0 TO payload_packet_length); --for output
     success_pkt : IN byte_array(0 TO 2); -- success to put, disconnect, abort
    obex_result_object : OUT obex_result;
    session_state : OUT state; -- state of OBEX session communication
     connect_pkt : OUT byte_array(0 TO 10); -- start obex session with connect
     put_pkt : OUT byte_array(0 TO payload_packet_length); -- put obex body
     get_pkt : OUT byte_array(0 TO 2); -- get results from server
     disconnect_pkt : OUT byte_array(0 TO 2); -- end session
    abort_pkt : OUT byte_array(0 TO 2); -- stop operation in the middle of a session
     timeout_error : OUT BIT -- indicate session has timed out
END obex_session;
```

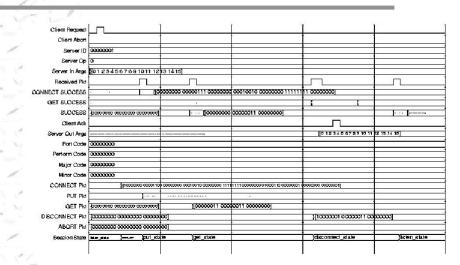


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Design

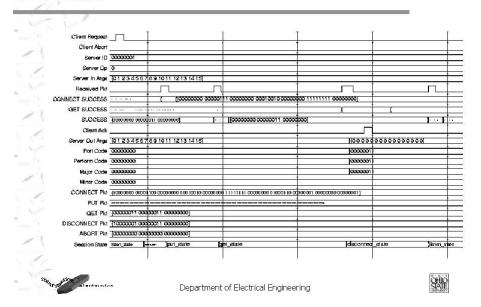
Client-Server VHDL Simulation





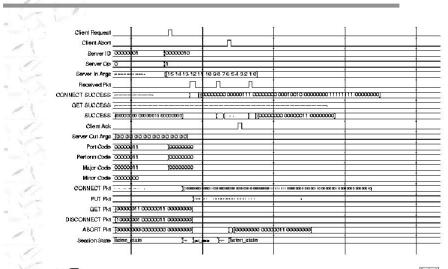


Server Responds with error



Client Abort

Design



Conclusions

- VHDL descriptions enables an implementation-oriented investigation of wireless sensor specifications.
- Easier to assess the feasibility and "cost" of various features by "what if" test bench scenarios.
- Easier to "visualize" complex behavior and catch potential problems.
- Prototyping for iterative specifications.



3.7 Development of Wireless Sensor Technology for Machine Monitoring



"Development of Wireless Sensor Technology for Machine Monitoring"

Dr. Mark F. Bocko Oceana Sensor Technologies Virginia Beach, VA

M. Bocko - Oceana Sensor Technologies - 6/4/01



Presentation Outline

- Machine monitoring applications of wireless intelligent sensors
- · Wireless intelligent sensor architecture
- Role of IEEE1451 in OST developments
- Summary



Proposed Approach

The equipment tells the people when it will need attention -

- Intelligent platforms built from
- Intelligent systems built from
- Intelligent components

...... in an open architecture

M. Bocko - Oceana Sensor Technologies - 6/4/01

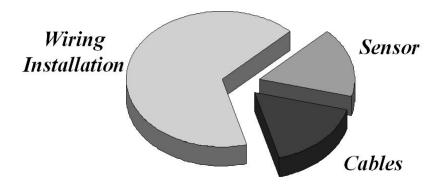


Types of sensing in machine monitoring

- · Vibration
- Force
- Pressure
- Temperature
- Electrostatic, magnetic (particulates)
- IR spectroscopy (fluid condition)
-



Typical Industrial Instrumentation Costs

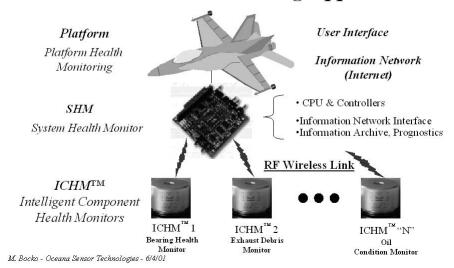


Wiring installation costs (including documentation) is limiting installation of needed sensors

M. Bocko - Oceana Sensor Technologies - 6/4/01



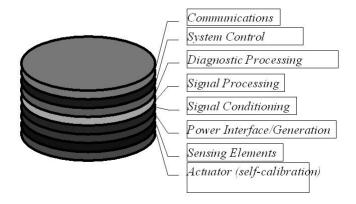
Machine Health Monitoring Application





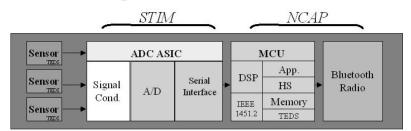
The layers of an ...

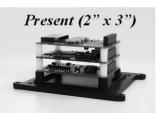
"Intelligent Component Health Monitor"



M. Bocko - Oceana Sensor Technologies - 6/4/01

Wireless Intelligent Sensor Architecture SENSOR Wireless e-Diagnostics*





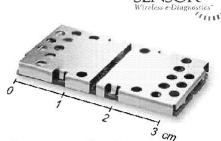
6 sensors, DSP, Bluetooth

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Target (2 chips)

92



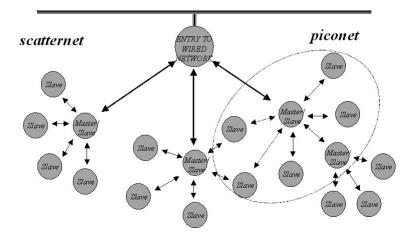


- · Bluetooth may become de facto standard
- · Digital spread spectrum, encrypted data
- · Flexible ad hoc networking
- Up to 760 kbit/s
- 1 mW-10 m; 100 mW-100m, ISM band
- · Will be single chip (CMOS) soon

M. Bocko - Oceana Sensor Technologies - 6/4/01



Bluetooth Networking





Wireless Issues in Industrial Automation

- · Over-the-air Interoperability
- · Synchronization
- · Latency
- Physical, Electro-Magnetic Environment
- Security

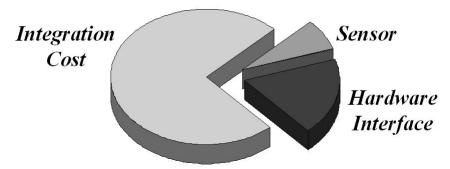
OST chairs a Bluetooth SIG Working Group to address these issues.

M. Bocko - Oceana Sensor Technologies - 6/4/01





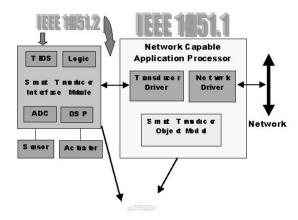
Typical Sensor Integration Costs



Sensor integration costs (including documentation) is limiting installation of needed sensors



IEEE1451 in the OST development plan



M. Bocko - Oceana Sensor Technologies - 6/4/01

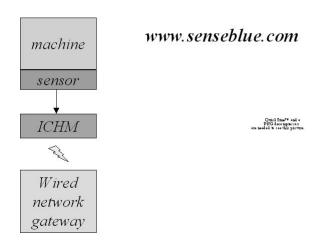


IEEE-1451 Transducer Interface Standard

- IEEE 1451.1
 - Defines the Transducer Object Model
- IEEE 1451.2
 - Defines the interface for integration of specific smart sensors to microprocessors
 - · Physical interface
 - TEDS
 - Protocol
- IEEE 1451.4
 - Defines an interface to bring TEDS functionality to legacy sensor systems



Demonstration



M. Bocko - Oceana Sensor Technologies - 6/4/01



Data carrying wires may be eliminated; can we remove power connections too?

- · Power grid is not always available
- Derive power from environment?
 - Vibration
 - Magnetic induction (rotating machines)
 - Solar
 - Thermal Energy Scavenging (hot machines)



"Plug and Play" → "Play"

- Key elements of strategy
 - Wireless communication
 - Open interoperable standards
 - IEEE1451
 - · Bluetooth wireless
 - Power scavenging

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